

# Tracking of Maximum Power Point Using Direct Control Algorithm with a DC-DC Converter and a BLDC motor for domestic application

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*Abstract—Among the renewable energy resources, the energy due to the photovoltaic (PV) effect can be considered the most essential and prerequisite sustainable resource because of the ubiquity, abundance, and sustainability of solar radiant energy. In this paper solar panel is designed based on single diode model. Incremental conductance based MPPT are implemented for directly controlling the duty ratio of cuk converter. Unlike the conventional MPPT which generates the reference voltage to be tracked by the converter, direct control MPPT generates duty ratio for switching the switch of a cuk converter. Hence by using this direct control, use of PI controller can be avoided, resulting in a simple control circuit. A Matlab/Simulink model of solar panel, cuk converter, is modeled. Incremental conductance algorithm for direct control is coded in matlab. Simulation analysis of performances is done at different operating conditions for PV array.*

**Index Terms—single diode model, MPPT, Incremental conductance, direct Control**

## I. INTRODUCTION

Nowadays application of solar energy has become a popular subject. It is well known that output power of solar array changes due to different circumstances including temperature, solar irradiation and so on. In order to give out the maximum power of the cells under variable circumstances, the maximum power point tracking (MPPT) strategy is proposed [1,4]. Due to rapid growth in the semiconductor and power electronics techniques and the Maximum Power Point Tracking (MPPT) methods [1], PV energy is of increasing interest in electrical power applications. Actually MPPT is a process of tracking the maximum power point under different solar irradiation and temperature through regulating the voltage of the solar array. The open-circuit voltage and short-circuit current of the solar array depends on solar irradiation and temperature. Hence, it is only through MPPT that we can extract as much energy as possible from a solar panel as a source under different conditions that exist. So MPPT methods have become a favorite field of solar generating based studies [5-9]. As the less than 30%, so it is important that we extract as much as possible from the PV so as to make it cost efficient renewable source of energy which in future may replace the existing conventional sources. So in order to perform the same many algorithms have been created to track point at which maximum power is obtained

### A. MPPT Methods

In order to increase the efficiency of solar array many MPPT methods have been formed. The MPPT algorithm operates based on the truth that the derivative of the output power (P) with respect to the panel voltage (V) is equal to zero at the maximum power point. In the literature, various MPP algorithms are available in order to improve the performance of photovoltaic system by effectively tracking the MPP. In all these years numerous MPP tracking methods have been proposed. They differ in many aspects such as complexity, accuracy, sensors that are required, cost or efficiency and also speed at which they track the point. Based on the control variable it uses, each method can be separated from one another. There are different MPPT techniques such as Perturb and Observe, Hill climbing, Incremental conductance, Fractional Short Circuit Current, Fractional Open Circuit Voltage, Fuzzy Control, and Neural Network Control etc. Among all these methods Perturb and observe (P&O) and Incremental conductance are used commonly. The most commonly used MPPT algorithm is P&O method. In this approach, the module voltage is periodically given a disturbance and the corresponding output power is compared with that at the previous perturbing cycle [6-7]. In this algorithm a slight perturbation is introduced to the system. This perturbation causes the power of the solar array to vary. If the power increases due to the perturbation then the perturbation is continued in the same direction else if the power reduces the perturbation is reversed in the opposite direction. After the peak power is reached the change in power is zero. In this method perturbation is not stopped even if MPP is reached. It is found that small power loss due to this perturbation also fails to track the maximum power under fast changing atmospheric conditions and when the stable condition is arrived the algorithm oscillates around the peak power point. The drawback of perturb and observe is overcome by incremental conductance algorithm, and it is able to track the peak power under fast varying atmospheric conditions. The Incremental Conductance can determine that the MPPT has reached the MPP and terminate perturbing the operating point. If this condition is not met, the direction in which the MPPT operating point must be perturbed can be calculated using the relationship between  $dI/dV$  and  $-I/V$ . This relationship is derived from the theory that  $dP/dV$  is negative when the MPPT is to the right side of PV curve of solar array and positive when it is to the left side [8-11]. But this algorithm is more complex

**II. MATHEMATICAL MODEL OF SOLAR CELL**

A solar cell is basically a p-n junction fabricated in a thin wafer of semiconductor. The electromagnetic radiation of solar energy can be directly converted to electricity through photovoltaic effect. Being exposed to the sunlight, photons with energy greater than the band-gap energy of the semiconductor creates some electron-hole pairs proportional to the incident irradiation.[2,3]. In this paper single diode modeling of solar cell is done as shown in fig 2. Equations relating to the diode current equations are used. Temperature dependence of saturation current is included to make the solar model more efficient. The equivalent circuit of a PV cell is as shown in Figure 1.

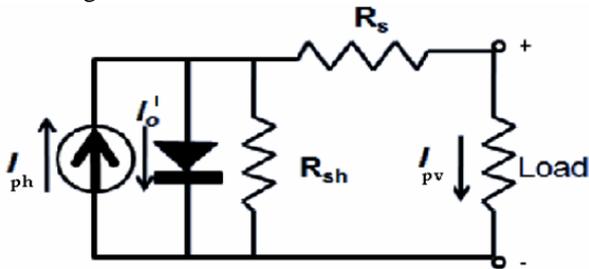


Fig. 1. The equivalent circuit of a solar cell

The current source  $I_{ph}$  represents the cell photocurrent.  $R_{sh}$  and  $R_s$  are the intrinsic shunt and series resistances of the cell, respectively. Usually the value of  $R_{sh}$  is very large and that of  $R_s$  is very small, hence they may be neglected to simplify the analysis. PV cells are grouped in larger units called PV modules which are further interconnected in a parallel-series configuration to form PV arrays.

The photovoltaic panel can be modeled mathematically as given in equations (1)- (6)

Current provided by the solar cell from the fig. 1 is given by  $I_{pv} = I_{ph} - I_o \dots (1)$

Where the current  $I_o$  is derived from the diode equation as follows, equation (2)

$$I_o = I_0 \left[ \exp \left\{ \frac{q * (V_{pv} + I_{pv} R_s)}{N_s A k T} \right\} - 1 \right] \quad (2)$$

Module photo-current  $I_{ph}$  given by equ.(3)

$$I_{ph} = [I_{scr} + K_i (T - 293) * I / 1000] \quad (3)$$

Module reverse saturation current -  $I_{rs}$  as in equation (4):

$$I_{rs} = I_{scr} \left[ \exp \left( \frac{q V_{oc}}{N_s k A T} \right) - 1 \right] \quad (4)$$

The module saturation current  $I_0$  as given in equation (5) varies with the cell temperature, which is given by

$$I_0 = I_{rs} \left[ \frac{T}{T_r} \right] \exp \left[ \frac{q * E_{go}}{B_k} \left\{ \frac{1}{T_r} - \frac{1}{T} \right\} \right] \quad (5)$$

The current output of PV module is in equation (6)

$$I_{pv} = N_p * I_{ph} - N_p * I_0 \left[ \exp \left\{ \frac{q * (V_{pv} + I_{pv} R_s)}{N_s A k T} \right\} - 1 \right] - \left( \frac{V + I R}{R_{sh}} \right) \quad (6)$$

$V_{oc}$ : open circuit voltage

$A$  : ideality factor (1.6)

$k$  : Boltzmann constant ( $1.38 \times 10^{-23}$  J<sup>o</sup>K).

$T_r$ : reference cell operating temperature

$q$  : electron charge ( $1.602 \times 10^{-19}$  C).

$K_i$  : short circuit current temperature coefficient at

$I_{scr} = .0017 A / ^\circ C$

$R_s$ : series resistance of cell

$R_{sh}$ : Parallel resistance.

$E_{go}$ : Band gap for silicon = 1.1 eV

$N_s$  : Number of series cell = 36

$N_p$  : Number of cell in parallel = 1

$I$  : Insolation ( $W/m^2$ )

**TABLE 1: Electrical characteristics data of pv module**

Rated Power	37.08 W
Voltage at Maximum power ( $V_{mp}$ )	16.56V
Current at Maximum power ( $I_{mp}$ )	2.25A
Open circuit voltage ( $V_{oc}$ )	21.24V
Short circuit current ( $I_{scr}$ )	2.55A
Total number of cells in series ( $N_s$ )	36
Total number of cells in parallel ( $N_p$ )	1

Note: The electrical specifications are under conditions irradiance of  $1kW/m^2$ , spectrum of 1.5 air mass and cell temperature of  $25^\circ C$ .

An efficient model of solar array is designed using current equations rather than voltage based equations.

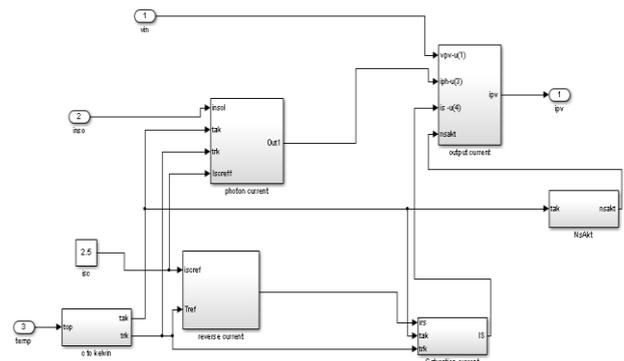


Fig 2. Matlab modeling of solar panel

**A. Performance Estimation**

I-V and P-V characteristics under varying irradiation with constant temperature are obtained as shown in Fig.3(a) to 3(b).

1. The I-V output characteristics of PV module with varying temperature at constant irradiation are shown in Figure 3(a).

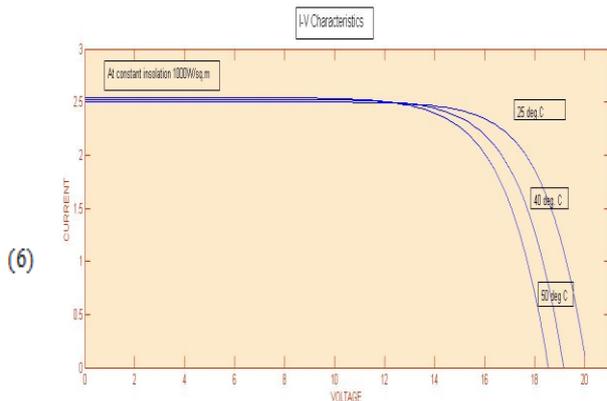


Fig 3 (a): I-V characteristics for varying temperature

2. The P-V output characteristics of PV module with varying temperature at constant irradiation are shown in Figure 3(b).

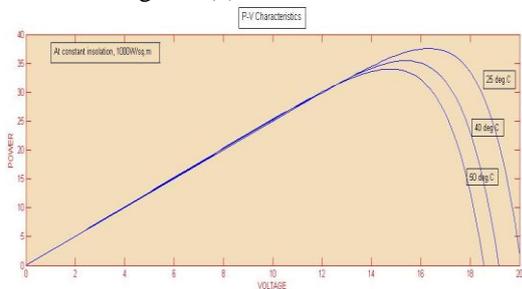


Fig 3(b): P-V characteristics for varying temperature

3. The I-V output characteristics of PV module with varying irradiation at constant temperature are shown in Figure 3(c).

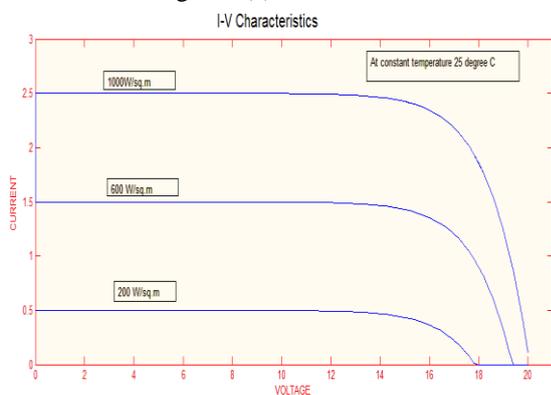


Fig 3(c): I-V characteristic for varying irradiation

4. The P-V output characteristics of PV module with varying irradiation at constant temperature are shown in Figure 3(d).

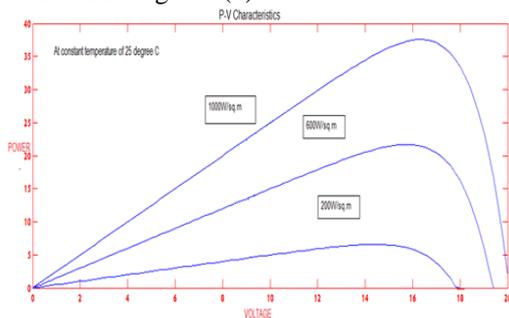


Fig 3(d): P-V characteristics for varying irradiation

### III. INCREMENTAL CONDUCTANCE MPPT

The output power of the solar PV module changes mainly with change in solar irradiation level and change in temperature. There exists a single maximum power point (MPP) in the PV characteristics of the PV array for a particular operating condition. It is desired that the PV module operates close to this point, i.e., output of the PV module approaches close to MPP as shown in Fig. 4. The process of operating PV module at this condition is called as maximum power point tracking (MPPT). Maximization of

power from PV improves the efficiency of the solar PV module.[12-15] The Incremental conductance (IC) which is derived from the idea of perturb and observe technique is used in this paper due to its advantages which overweighs its disadvantages. The IC can determine that the MPPT has reached the MPP and stop perturbing the operating point. The algorithm of incremental conductance is given in fig.8 below. At MPP, according to P-V characteristic we have,

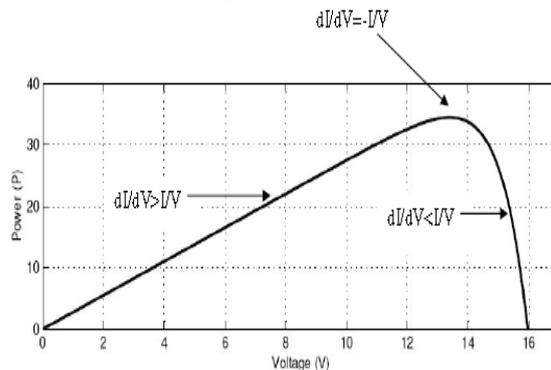


Fig.4. Maximum Power Point

$$\frac{dP}{dV} = \frac{d(V * I)}{dV} = 0$$

$$\frac{d(V * I)}{dV} = V * \frac{d(I)}{dV} + \frac{dV}{dV} * I = 0$$

$$\frac{dI}{dV} = -\frac{I}{V} \text{ is the condition at MPP}$$

#### A. Conventional method for MPPT

In conventional method for implementing the MPPT technique, included a PI controller as shown in fig 5. In this method the incremental conductance algorithm generates a reference voltage  $V_{ref}$ , which is compared with the voltage measured and the error is made to pass through the controller in order to minimize the error, i.e. the measured voltage is made to track the reference voltage.[15]

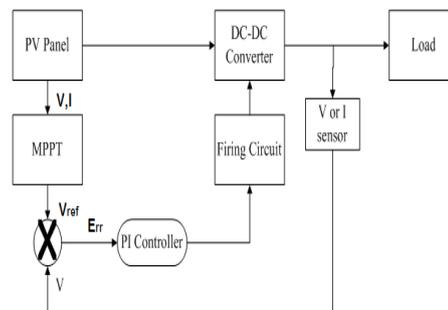


Fig 5: Conventional MPPT control method

#### B. Direct Control MPPT

In direct control method unlike the conventional method the duty cycle of the converter is the output of the MPPT algorithm and not the reference voltage  $V_{ref}$ . Hence the measured voltage is not tracked to the reference voltage using

PI controller. Thus the control circuit made simple and easier to implement. PI controller. The direct control method which shown in fig. 6 is simpler and uses only one control loop, it performs the adjustment of duty cycle within the MPP tracking algorithm. The way to adjust the duty cycle is totally based on the theory of load matching.

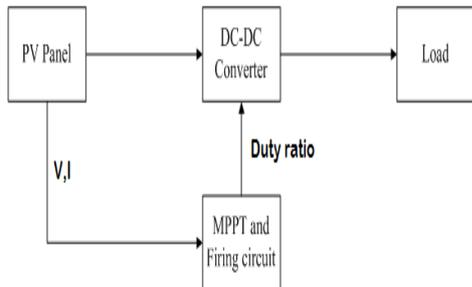


Fig.6. Direct control method

**Mechanism of Load Matching**

According to maximum power transfer theorem, maximum power is transferred from the source to the load when the load impedance matches to the source impedance. This theorem is utilized in Direct control method for transferring maximum power from a solar cell in to the load. In this paper a cuk converter is used as the DC –DC converter which connects the load to the solar panel.[13,14] The resistance of the solar cell at optimal point is in equation(7)

$$R_{opt} = \frac{V_M}{I_M} \quad (7)$$

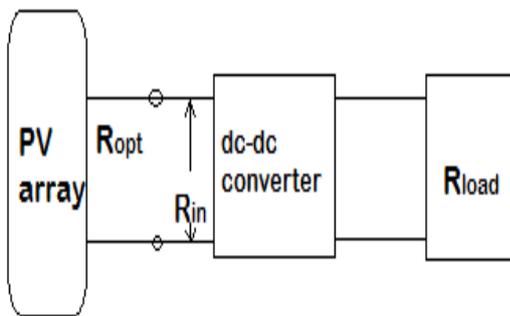


Fig 7: load impedance matching

From the fig.7 the load resistance is fixed, which in turn is related to the input impedance given by equation (8) of the converter, Rin by the duty ratio of the cuk converter D. Thus flow of maximum power occurs when input impedance of the converter matches with the optimal resistance of the solar cell at MPP.

$$R_{in} = \frac{V_s}{I_s} = \frac{(1-D)^2}{D^2} * \frac{V_{load}}{R_{load}} = \frac{(1-D)^2}{D^2} * R_{lo} \quad (8)$$

In the direct control algorithm change in current and change in voltage is calculated to find if incremental conductance (I/V) and instantaneous conductance ( ) and when this two conductance are equal maximum power point is reached.

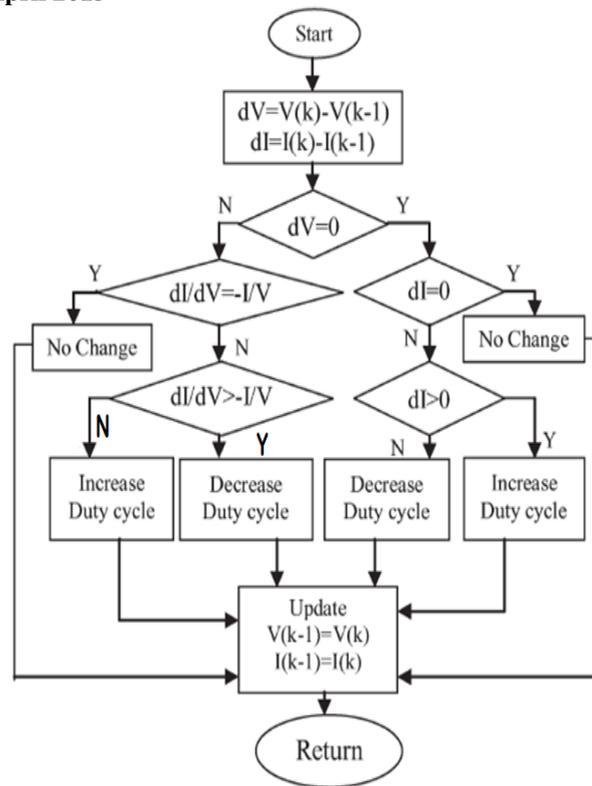


Fig. 8: Direct control incremental conductance algorithm

**IV. MODELING OF CUK CONVERTER**

**A. Working Principle**

Among all the topologies available, both Cuk and buck–boost converters provide the opportunity to have either higher or lower output voltage compared with the input voltage. Although the buck–boost configuration is cheaper than the Cuk one, some disadvantages, such as discontinuous input current, high peak currents in power components, and poor transient response, make it less efficient. On the other hand, the Cuk converter has low switching losses and the highest efficiency among non-isolated dc–dc converters and less current ripple. A non-isolated Cuk converter comprises two inductor two capacitors, a switch, and a diode. Its schematic can be seen in fig. 9. It is an inverting converter, so the output voltage is negative with respect to the input voltage. The capacitor C is used to transfer energy and is connected alternately to the input and to the output of the converter via the commutation of the transistor and the diode. The two inductors L1 and L2 are used to convert respectively the input voltage source (Vs) and the output voltage source (Co) into current sources. At a short time scale an inductor can be considered as a current source as it maintains a constant current. This conversion is necessary because if the capacitor were connected directly to the voltage source, the current would be limited only by the parasitic resistance, resulting in high energy loss. Charging a capacitor with a current source (the inductor) prevents resistive current limiting and its associated energy loss.

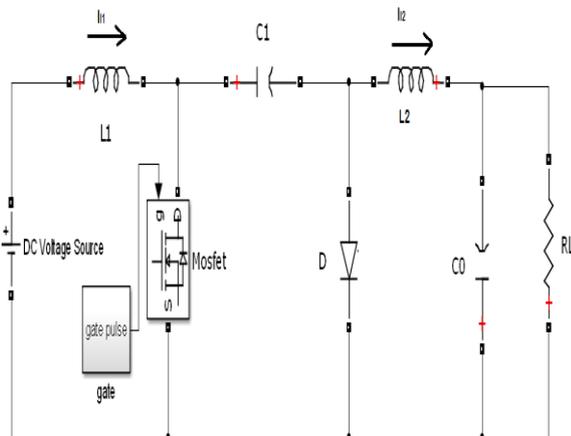


Fig. 9: Cuk converter circuit diagram

For a cuk converter we have relationship between output and input voltage as in equation.(9)

$$\frac{V_{out}}{V_{in}} = \frac{D}{1-D} = \frac{I_i}{I_o} \quad (9)$$

**B. Design equations**

A cuk converter consists of two inductors which are used to reduce the output ripple current, thus the inductor value of both the inductor are identical. The inductance value is found by using equation (10) and (11),

$$\Delta I_1 = \frac{V_{in} * D}{L_1 * f} \quad (10)$$

$$\Delta I_2 = \frac{V_{in} * D}{L_2 * f} \quad (11)$$

Where,  $\Delta I_1, \Delta I_2$  are ripple current and  $V_{in}$  is the input current to the cuk converter and  $f$  is the switching frequency and it is taken as 10 KHz. The ripple is assumed to be 10 %.

The capacitor  $C_1$  acts as the coupling capacitor and the value of capacitance is decided by equation (12)

$$\Delta V_{c1} = \frac{I_1 (1 - D)}{C_1 * f} \quad (12)$$

The capacitor  $C_2$  acts as a filter capacitor and its capacitance is obtained by (13)

$$\Delta V_{c2} = \frac{I}{8C} \quad (13)$$

Thus the value of inductance and the capacitance is obtained.

**V. BRUSHLESS DC MOTOR**

In this paper a BLDC motor is used as the load. A three-phase BLDC motor requires three Hall sensors to detect the rotor's position. Based on the physical position of the Hall sensors, there are two types of output: a 60° phase shift and a 120° phase shift. Combining these three Hall sensor signals can determine the exact commutation sequence.[16]

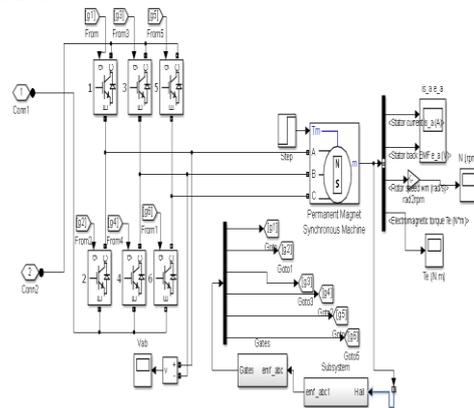


Fig 11: Matlab model of BLDC motor

**VI. SIMULATION RESULTS**

A solar panel of 36W is connecting to a non-isolated DC-DC converter; a cuk converter is used in this simulation. An incremental conductance algorithm for directly controlling the duty cycle of the converter is coded in MATLAB/Simulink and gating pulses are provided by comparing the duty ratio with triangular wave.

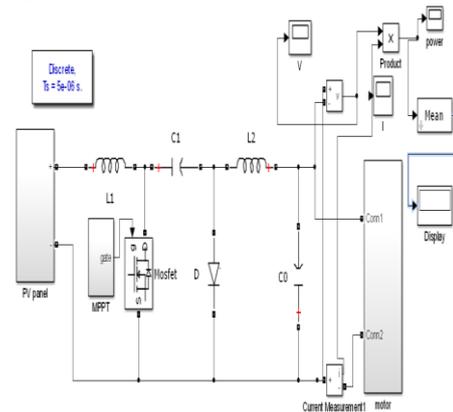


Fig.12. Matlab/Simulink model of the proposed direct control MPPT using cuk converter

Table 2.Simulation parameters of cuk converter

Cuk converter parameters	
L <sub>1</sub>	100µH
L <sub>2</sub>	100µH
C <sub>1</sub>	47µF
C <sub>2</sub>	4.7µF
Switching frequency	10KHz
R <sub>load</sub>	4Ω

The PV system is made to operate on different conditions such as varying insolation and varying temperature.

**A. Case1 (varying irradiation level)**

Initially an irradiation level of 200W/m<sup>2</sup> at a temperature of 25°C for 2 seconds followed by an increase in irradiation to 600W/m<sup>2</sup> for another 2 seconds with the same temperature. It is observed that the duty ratio increases and so does the voltage and power. The irradiation is again changed to 1000W/m<sup>2</sup> and further increase in maximum power and voltage was observed. Maximum power is tracked by

adjusting the duty ratio of the cuk converter as shown in Fig. 13(a) – 13(c).

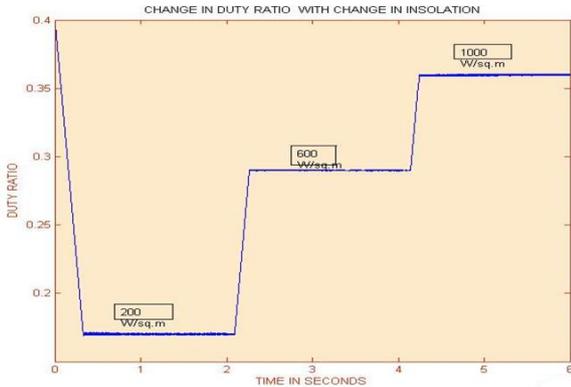


Fig 13(a): duty ratio with change in irradiation

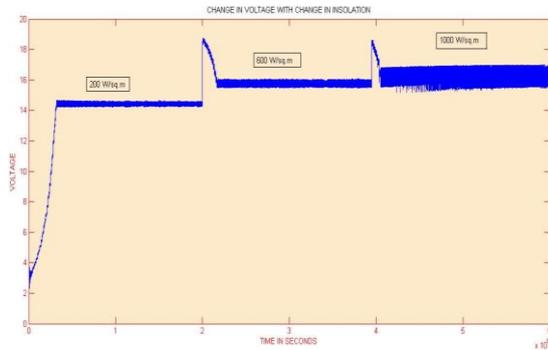


Fig 13(b) : voltage with change in irradiation

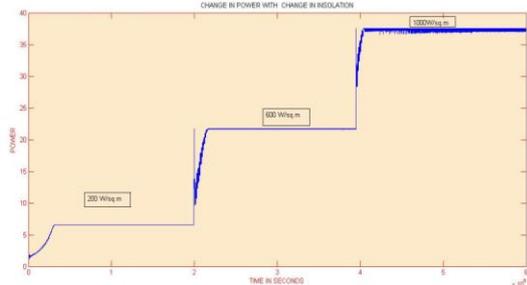


Fig 13(c) : Change in power with increase in irradiation

**B. Case2 (varying temperature)**

In second case to show how MPPT is tracked for a variation of temperature level at constant insolation of 1000W/m<sup>2</sup>. Initially the temperature is 15°C for 2 sec ,which is then increased to 25°C,its observed that with the increase in temperature the duty ratio is increased were as the power is reduced and so the voltage as shown in fig.13(a) -13(c)

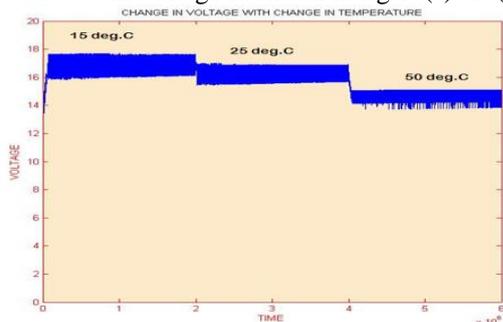


Fig 14(a) : change in voltage with change in temperature

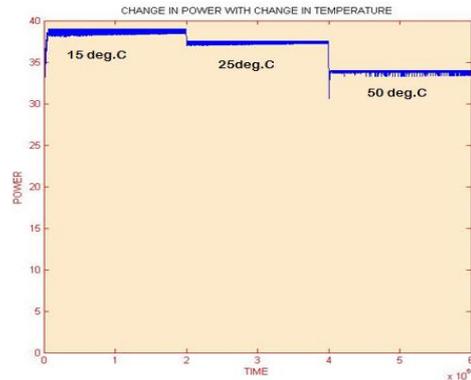


Fig14 (b): Change in power with change in temperature

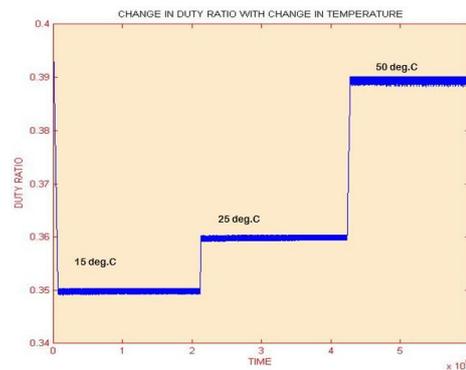


Fig 14(c): Change in dutyratio with change in temperature

**C. Simulation result of the BLDC motor output at a constant insolation of 1000W/m<sup>2</sup> and 25°C standard temperature**

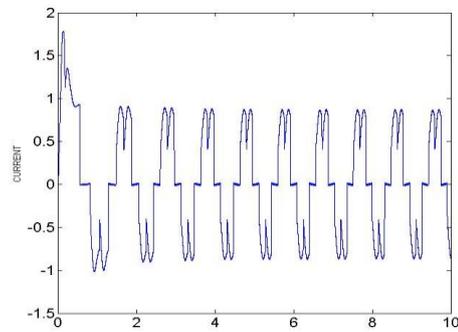


Fig 15: stator current of the motor

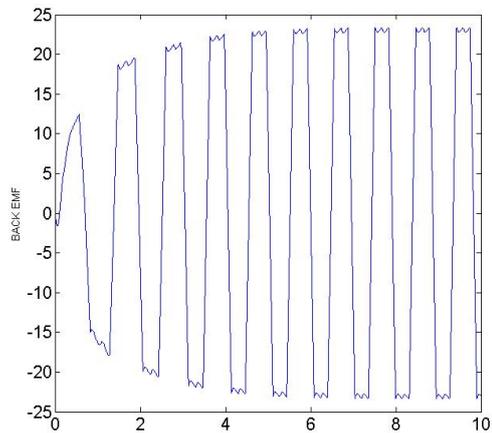


Fig.16: Stator back emf of phase a

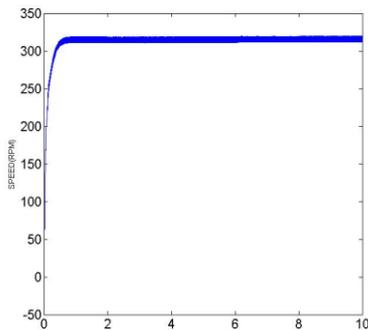


Fig.17: Speed of the rotor in rpm

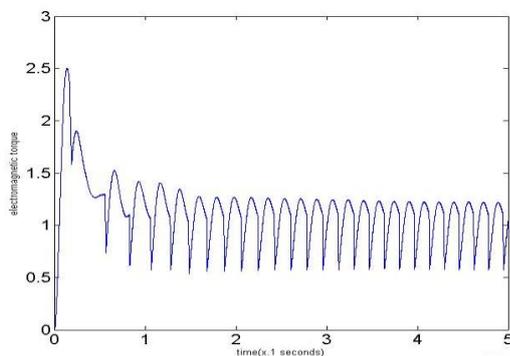


Fig.17: Electromagnetic torque ( $t_e$ )

## VII. CONCLUSION

The paper proposed the modeling of a solar panel based on the current equations and an incremental conductance MPPT algorithm is used to control the duty ratio of the Cuk converter which in turn adjusts the resistance such that load resistance equals the source resistance and maximum power of the solar panel is tracked. The advantage of this direct control is that it eliminates the use of PI controller. The PI control loop is eliminated, and the duty cycle is adjusted directly in the algorithm. The control loop is simplified, and the computational time for tuning controller gains is eliminated. The implementation of MPPT is simple and can be easily constructed with an acceptable efficiency level of the PV array. Also the use of cuk converter reduces the ripple compared to buck-boost converters. The proposed system was simulated and the functionality of the suggested control concept was proven.

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